



MEMO

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To: Montana Board of Environmental Review

CC: Eric Urban, Water Quality Standards Section Supervisor

From: Michael Suplee, Ph.D., and Kyle Flynn, P.H., Environmental Science Specialists, Montana Dept. of Environmental Quality

Date: 3/19/2014

RE: Derivation of the Seasonal 14Q5 Low-flow Design Flow for Wadeable Streams and Large Rivers

When Montana Pollutant Discharge Elimination System (MPDES) permits are developed, a low-flow design flow is routinely used to calculate a permittee's allowable discharge concentrations. The Department uses a seven-day, ten-year design flow (7Q10) for permitting pollutant discharges (ARM 17.30.635(2)). But this low-flow was designed primarily for toxics and has year-round application. Existing rule directs the Department to identify a low-flow design flow specific to nutrients (ARM 17.30.635(2)). Therefore, we explored alternative design flows that might be more appropriate for discharges containing nitrogen and phosphorus (nutrients) and which could be applied seasonally to the proposed base numeric nutrient standards in MAR notice No. 17-356.

The result of our work was the seasonal 14Q5 low-flow design flow. Rules (e.g., ARM 17.30.635) have been modified to include the seasonal 14Q5 and these modifications are also found in MAR notice No. 17-356. The seasonal 14Q5 low-flow is **specific to discharges containing nutrients**. The purpose of this memo is to describe the process by which this nutrient-specific low-flow design flow was developed.

Development of the 14Q5 Low-flow Design Flow for Discharges Containing Nitrogen and Phosphorus

The most important low-flow design period for nutrients is the summer and fall baseflow period (growing season), when water quality is most likely to be impaired by excess nutrients. Streams in Montana tend to reach stable baseflow, elevated temperatures, greatest water clarity, and maximum photoperiod at about the same time, beginning in late June or early July (Suplee et al., 2007). In large rivers this period generally begins later, usually around August 1st (Flynn and Suplee, 2013). The point in time in the fall/early winter when this growing season ends is somewhat subjective, but based on rapidly declining temperatures, diminished light levels, etc., sometime in October is probably appropriate. Given these considerations, then, the growing season is the most logical time for the application of nutrient standards and a seasonal low-flow design flow.

Algal growth rates govern the time required to reach a given algal biomass. They are dependent on temperature, light, and nutrient limitation, and are the precursor to all the attendant eutrophication responses. It is therefore necessary to constrain loadings (i.e., limit nutrient concentrations) over durations when nuisance growth and associated water quality excursions are expected to (and can physically) occur. Since bottom-attached (benthic) algae have been shown to be very influential to river and stream primary productivity (Stevenson et al., 1996), benthic algal growth rates from the literature (**Table 1**) were used in conjunction with a simple analytical model to derive a suitable duration for appraisal of river and stream water-quality. The model (presented below) provides a low-flow design flow supportive of river beneficial uses.

Table 1. Enrichment Studies and Associated Net-specific Growth Rates Adjusted to 20 Degrees C. Growth rates were corrected to the reference temperature using the Arrhenius equation (Chapra et al., 2008).

Algae Type	Net Specific Growth Rate at 20°C (k, day ⁻¹)	Reference	Location	Comment
Diatoms	0.50	Klarich (1977)	Yellowstone River, MT	Near Huntley Billings WWTP
Diatoms	0.55	Bothwell and Stockner (1980)	McKenzie River, OR	5% kraft mill effluent
<i>Cladophora</i>	0.71	Auer and Canale (1982)	Lake Huron, MI	Harbor Beach WWTP
Green algae	0.52	Horner et al. (1983)	Lab Flume	Laboratory N & P addition
Diatoms	0.42	Bothwell (1985)	Thompson River, BC	Downstream of WWTP
Diatoms	0.62	Bothwell (1988)	S. Thompson River, BC	Flume with N & P addition
Diatoms	0.58	Biggs (1990)	South Brook, New Zealand	Downstream of WWTP
Diatoms	0.45	Stevenson (1990)	Wilson Creek, KY	Agricultural stream after spate

Growth of stream and river benthic algae typically follows a general pattern of colonization, exponential growth, and autogenic sloughing and loss (Stevenson et al., 2006). The net accrual portion (i.e., colonization and growth) can be readily modeled using a first-order exponential net growth equation (**Equation 1**), with space limitation (**Equation 2**), per Chapra et al. (2010),

$$\frac{da_b}{dt} = a_b \phi_{sb} k \quad (1)$$

$$\phi_{sb} = 1 - \frac{a_b}{a_{b,max}} \quad (2)$$

where a_b = benthic algal biomass (mg Chla/m²), ϕ_{sb} = a space limitation factor (dimensionless), k = temperature dependent first-order net-specific growth rate (day⁻¹), and $a_{b,max}$ = maximum biomass carrying capacity (mg Chla/m²). Equations 1 and 2 can be combined and solved analytically (**Equation 3**),

$$a_b(t) = \frac{a_{b,max} \exp^{kt}}{\frac{a_{b,max}}{a_{b,init}} + \exp^{kt} - 1} \quad (3)$$

where $a_b(t)$ = benthic algal biomass (mg Chla/m²) at a defined point in time after growth initiation, $a_{b,init}$ = initial biomass condition (mg Chla/m²), and t = time (days), so that peak biomass (PB) and time to peak biomass (T_{PB}) (per Stevenson et al., 2006) can be identified (**Figure 1**). For the design flow determination, an initial biomass of 0.1 mg Chla/m² was assumed for all growth calculations with an $a_{b,max}$ of 1000 mg Chla/m² (Horner et al., 1983).

We further define additional points of interest in the accrual curve (**Figure 1**), namely nuisance biomass (NB) and time to nuisance biomass (T_{NB}). These occur between the initial colonization phase and PB and reflect the point where a nuisance response would occur absent of nutrient limitation. For a nutrient control strategy to be effective, benthic algal biomass must be \leq NB and nutrients constrained so that PB never reaches NB. We defined NB as >150 mg Chla/m² (Suplee et al., 2009).

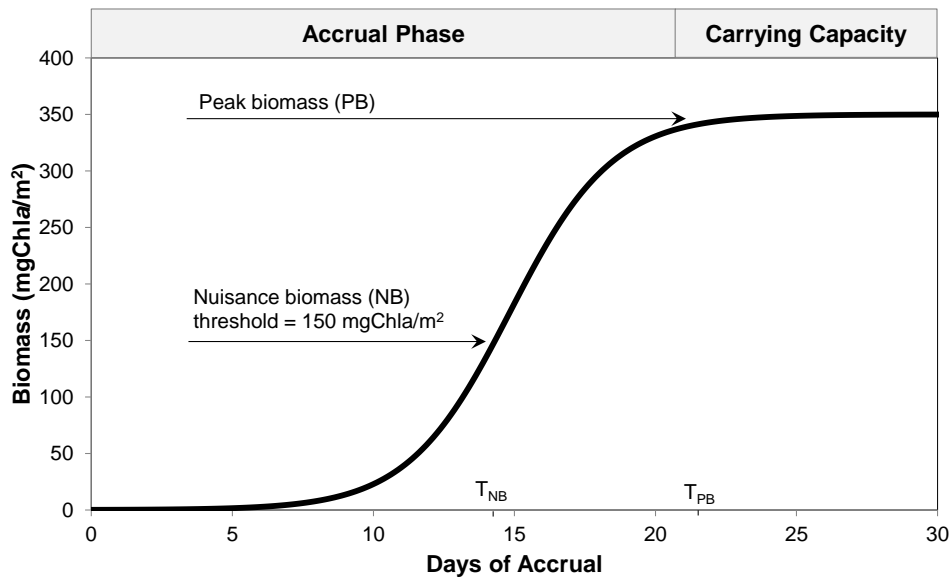


Figure 1. Modeled Accrual Phase for Benthic Algae Showing Colonization, Exponential Growth, and Peak Biomass. Time to peak biomass and nuisance biomass are shown on the abscissa.

Studies with moderate nutrient enrichment and time-variable benthic algal biomass measurements were compiled (**Table 1**) so that T_{NB} , PB , and T_{PB} could be estimated for nutrient concentrations similar to the proposed standards. We only considered studies that reported water temperature so that corrections to a standard reference temperature (20°C) could be made, and the Arrhenius equation was used to make these adjustments (Chapra, 2008). Light was not believed to be a limiting factor in the compiled studies. Temperature-normalized growth coefficients (k ; day⁻¹, 20°C) averaged 0.55 ± 0.09 /day (95% confidence level) and, using **Equation 3** above, yielded times-to-nuisance biomass from 11-17 days, with an average of 14 days (**Figure 2**). Fourteen days closely matched the T_{NB} determined for the Yellowstone River (Klarich, 1977) and was selected as the duration interval. The 14-day T_{NB} applies to shallow areas (< 0.5 m) of large rivers, as well as to wadeable streams which normally have shallow depths in summer.

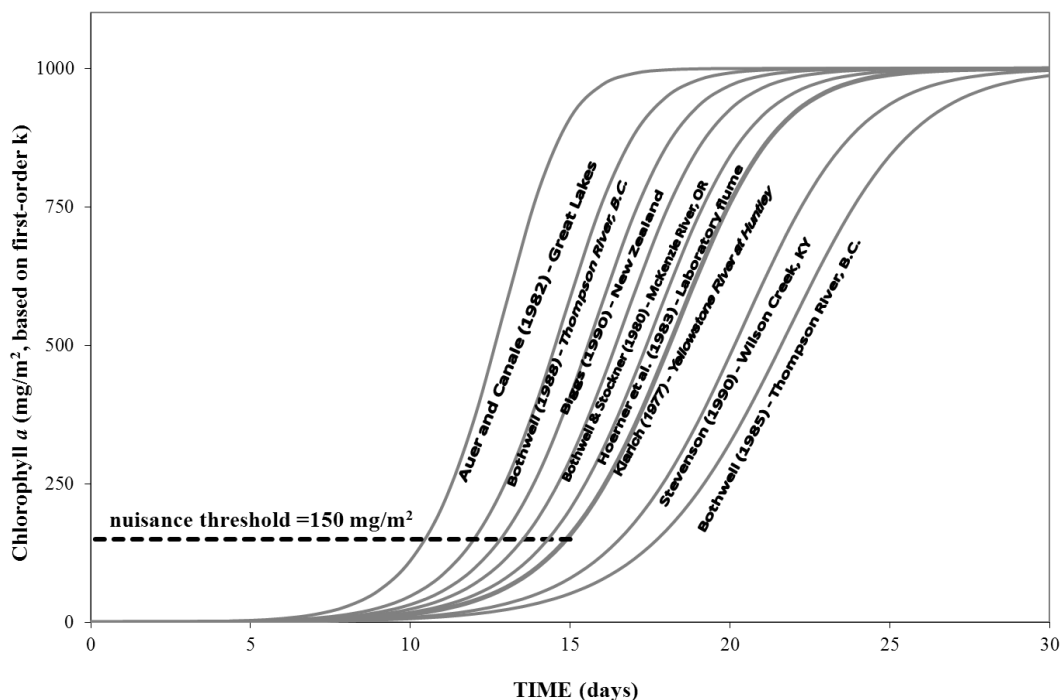


Figure 2. Estimated Time to Nuisance Algal Biomass under Moderately Enriched Conditions. Each curve was generated using the k values in Table 1. Time to nuisance biomass was approximately 14 days.

The time to nuisance biomass estimate (14 days) could actually be lower or higher than 14 days and warrants further consideration. The time to nuisance depends, in part, on the initial biomass used. It is possible that the initial biomass we used for the growth curves (0.1 mg Chl a/m^2 ; **Figure 2**) was too low, and the algae standing crop more common in summer ($5\text{-}50 \text{ mg Chl a/m}^2$) would rise to a nuisance level more quickly than estimated. But if the proposed nutrient standards induce a lower level of enrichment than assumed (i.e., a reduced k , or growth coefficient), the time to nuisance biomass is extended and would lengthen the associated duration beyond 14 days. These two uncertainties will tend to counter-balance one another, and we concluded that 14 days is a good approximation of the central tendency of the modeled results.

We then considered the 14-day duration in the context of the results from a whole-stream enrichment study carried out by the Department in a Montana stream (Suplee and Sada de Suplee, 2011). In the

enrichment study, peak algal biomass at the location in the study reach with the most algae—as documented by photo series and quantitative measurement—occurred about 20 days after N and P dosing began. Dosing was set at moderately-enriched levels and the algal biomass peaked at the location at 1,092 mg Chl a /m 2 , a density nearly identical to the maximum value we assumed in **Equation 3**. (The biomass peak comprised filamentous algae, not diatoms.) Initial algal biomass in the stream at the study site was around 40 mg Chl a /m 2 . The average stream water temperature over the time period was 21.8°C (range 16.2°C to 28.9°C), very close to the reference temperature of 20°C used in **Equation 3**. Note that the 20-day time-to-peak-biomass from the stream enrichment study closely aligns with the time-to-peak (T_{PB}) biomass in the modeled results (**Figure 2**). Taken together, the laboratory studies (**Table 1**), the modeled results (**Figure 2**), and the results from the stream-enrichment study indicate that 14 days is an appropriate duration for nutrient control to maintain benthic algae below nuisance levels.

Recurrence frequency of low-flow events is the second consideration. The U.S. Environmental Protection Agency (USEPA) recommends a site-specific, biologically-driven approach for permitting discharges, where the average concentration of a toxic pollutant to which aquatic life can be chronically exposed without deleterious effects over a 4-day period should not occur more than once every 3 years (Stephan et al., 1985). Four days equates to the duration of exposure, once in three years the allowable recurrence frequency. In theory, this approach ensures excursions of toxic pollutants are uncommon enough that sufficient time passes for the aquatic community to recover in the interim years. Excess nutrient concentrations also lead to biological changes and impacts which then require time for recovery, therefore a recurrence frequency of about once every three years is probably a good starting point for nutrient pollution. Accordingly, we selected a seasonal (July 1 to October 1) 14Q5 flow as the design flow for application to nutrient standards to be slightly protective. The 14-day duration reflects the time it can take to achieve nuisance biomass in wadeable streams and shallow parts of large rivers if nutrients are elevated (fewer days would be more-protective, more days less-protective). The 5-year recurrence frequency is close to USEPA’s long-standing recommendation (i.e., once in three years) while being slightly protective. And, the seasonal 14Q5 flow is routinely reported by the U.S. Geological Survey (McCarthy, 2004), therefore it is readily available for use in MPDES discharge permits.

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